A WTP MODEL SHOWING THE RELATIONSHIPS BETWEEN THREE APPROACHES FOR POLLUTION CONTROL

ABSTRACT

In this paper, a simple willingness to pay (WTP) model that shows the theoretical relationships among three valuation approaches that can be used to measure changes in health resulting from pollution is developed. The three valuation approaches considered are the contingent valuation (CV), cost of illness (COI) and the defensive behaviour approaches. After showing the relationships between the three valuation approaches, the model demonstrates that the CV approach exceeds the COI and the defensive behaviour approaches. The theoretical results are supported by field survey data. The pollution referred to in this paper is direct exposure to pesticides by farmers during handling and spraying on their farms.

1. INTRODUCTION

It has been shown that many valuation techniques could be used to measure changes in health resulting from pollution. In this paper, a simple willingness to pay (WTP) model is developed to show the theoretical relationships among three commonly used valuation approaches. The three approaches considered are the contingent valuation (CV), cost of illness (COI) and the defensive behaviour approaches. The CV approach, which involves asking people what they are willing to pay to reduce/avoid[1] the number of symptom days or illnesses they experience as a result of exposure to pollution. The defensive behaviour approach infers peoples' WTP to reduce or avoid[2] exposure to pollution from the amounts of money they spend on precautionary action taken. The COI approach on the other hand uses available data on medical expenditures and other costs (out-of-pocket expenses), as well as opportunity costs (foregone earnings being the most obvious example), to infer a lower bound to WTP to reduce pollution.[3] Both these approaches, unlike the CV method are indirect approaches used in inferring individuals' WTP for pollution control.

In the first Section of this paper, a simple WTP model is developed to show the relationships between three commonly used valuation approaches and then demonstrate how the CV

[1] The field study gathered CV bids to avoid exposure to pesticides.
[2] In the paper the WTP to reduce exposure to pesticides from COI and defensive behaviour is inferred from data collected from the field survey.
[3] For a discussion on the COI approach being a lower bound to WTP for a reduction in pollution, see Kenkel (1994).

approach takes into consideration all costs, including intangible costs. In Section II, the WTP for pollution control is estimated using the three approaches from a field survey carried out in Sri Lanka. The pollution referred to in this paper is direct exposure to pesticides by farmers during handling and spraying on their farms.

2. THE WILLINGNESS TO PAY MODEL

Models that describe what an individual is willing to pay for improvements in health resulting from exposure to pollution are well known in the literature (Rowe And Chestnut, 1984; Gerking and Stanley, 1986; Harrington and Portney, 1987; Harrington et al., 1989; Cropper and Freeman, 1991). This section develops a theoretical framework based upon the health production function model of Cropper and Freeman (1991, p.194-196) to show the relationships among the CV, COI and the defensive behaviour approaches.

Pesticides, like chemical fertilisers, are an essential input in the cultivation of high yielding commercially grown crops. They are essential because these crops are highly susceptible to pests and diseases. Hence, farmers are dependent on the use of pesticides, without which they are unable to cultivate high yielding commercial crops successfully. It is interesting to note that by 1982 the percentage of the cultivation of high yielding varieties in rice in Sri Lanka was 94% (Abeygunawardena and Bessler, 1989). This shows the extent to which farmers are dependent on chemical inputs such as pesticides. Farmers handling and spraying pesticides on farms often suffer from numerous health effects as a result of direct exposure to pesticides. Deaths are also not uncommon.

In this model, the health outcome of interest is the time spent sick, i.e. the time an individual spends ill due to direct exposure to pesticides[4]. Defensive behaviour and the level of medical treatment are considered in the model and for ease of presentation only one of each is assumed at one time.

The relationships in the model can be described as follows: The number of days or hours spent sick (S), is a function of exposure to pesticides (E), and the level of medical treatment

[4] Farmers are exposed to pesticides in small quantities on a typical pesticide spraying day but nevertheless suffer from many adverse health effects. For recorded adverse health effects among farmers see (Wilson, 1998).

(M), which can be written as follows:

$$S = S(E, M) \tag{1}$$

where $S_E > 0$ and $S_M < 0$.

Medical treatment includes hospitalisation, visits to a doctor or simply taking home-made self-treatment, which nevertheless incurs a monetary and time cost.

It is also well known that the level of exposure (E) is a function of the level of avoidance through defensive behaviour (D), and the level of pollution (P).

$$E = E(D, P) \tag{2}$$

where $E_D < 0$ and $E_P > 0$ and $E_{DD} < 0$ and $E_{PP} > 0$.

The defensive activities could include the following: using protective clothing, wearing masks, gloves, shoes during spraying, hiring labour to spray pesticides and so on. Purchasing protective gear involves costs as well as time spent in purchasing and maintaining them.

Substituting for E in equation (1) gives the following function:

$$S = S(E(D, P), M) \tag{3}$$

Any ill health resulting from exposure to pesticides affects the individual's utility (welfare) by causing discomfort, pain, suffering and also affects the amount of time (and possibly money) available for the consumption of goods and leisure activities (X). The utility (welfare) function can then be written as:

$$U = U(X, S) \tag{4}$$

where $U_X > 0$ and $U_S < 0$ and $U_{XX} < 0$ and $U_{SS} < 0$.

or equivalently

$$U = U[X, S(E(D, P), M)] \tag{5}$$

The time spent sick has an impact on the budget constraint by reducing the time spent at work and the amount of income earned. Time spent sick also affects leisure activities. Taking these into consideration, the individual faces the following budget and time constraints:

$$P_X X + P_D D + P_M M = T_w w + I \tag{6}$$

$$T_X X + T_D D + T_M M + S + T_w = T \tag{7}$$

P_K is the price per unit of K, for $K = X, D$ or M, T_K is the time per unit of K, for $K = X, D$ or M, T_w is the time spent working[5], w is the individual's wage rate, I is the non wage income, and T the total time available.

Following Rowe and Chestnut (1984, p.4), it is possible to compute the "full income" constraint by assuming all time[6] is valued at the wage rate[7], and defining Q_K as a combined monetary value and time cost: $Q_K = P_K + wT_K$ to obtain:

$$Q_X X + Q_D D + Q_M M + wS = wT_w + I \tag{8}$$

The individual's decision problem can then be expressed as:

$$\underset{X,D,M}{Max}\; U[X, S(E(D,P), M)] \tag{9}$$

$$\text{s.t. } Q_X X + Q_D D + Q_M M + wS = wT_w + I$$

In order to show the relationships among the three valuation approaches used in this paper to value the health benefits arising from a reduction in *P*, it is necessary to consider the expenditure function. As stated by Cropper and Freeman (1991), economists define an individual's expenditure function as the minimum value of expenditure minus the wage income necessary to keep his/her utility at a given level, U^0. In equation form it can be written as follows:

[5] Here reference should be made to earnings from work from the farm since farmers are self-employed. However, for ease of presentation wT_w. is employed.

[6] Time is essential because those suffering from health effects, not only incur out-of-pocket costs and lost earnings from inability to work and loss of productivity but also suffer from loss of leisure time due to illnesses and travelling to and from hospital to seek medical treatment, etc.

[7] For example, see Kenkel (1994) who values all time at the wage rate.

$$E = \underset{X,D,M}{Min}\left\{XQ_X + DQ_D + MQ_M - w\left(T - S\left(E\left(D,P\right),M\right)\right) + \lambda\left(\overline{U} - U\left(X,S\left(E\left(D,P\right),M\right)\right)\right)\right\} \quad (10)$$

where E[8] is expenditure and λ is the Lagrangian multiplier. By applying the envelope theorem to Equation (10) and substituting from the first-order conditions for expenditure minimisation, the WTP for a marginal change in P, ∂E/∂P, can be written as:

$$WTP = -\left(\partial S/\partial P\right)Q_M / \left(\partial S/\partial M\right) = -Q_M\left(\partial M/\partial P\right) > 0 \quad (11a)$$

$$WTP = -\left(\partial S/\partial P\right)Q_D / \left(\partial S/\partial D\right) = -Q_D\left(\partial D/\partial P\right) > 0 \quad (11b)$$

$$WTP = \left(\partial S/\partial P\right)WTP_S \quad (11c)$$

The proof is shown in Appendix 1

where $WTP_S = (\partial E/\partial S)$. As Cropper and Freeman (1991) point out, it is possible to show from the above three equations in (11) that WTP is given by the change in sick time associated with a change in the level of pollution, ∂S/∂P, multiplied by the marginal cost of pollution. The marginal cost of pollution can be any medical expenditures and other costs associated with ill health (COI expenditures), precautionary behaviour (defensive expenses), or simply what an individual would be willing to pay to bring about a change in exposure to pollution and the resulting ill health (the direct CV approach). A reduction in the number of sick days can be brought about by increased medical expenditures and associated costs, i.e. ∂S/∂M, or alternatively by increased defensive behaviour, i.e. ∂S/∂D or even by a combination of all these activities.

According to Equation (11a), WTP can be estimated from the changes in medical expenditures and associated costs brought about by changes in pesticide pollution, ∂M/∂P, which are reflected in the costs of mitigating behaviour, Q_M. Hence
WTP = $-Q_M(\partial M/\partial P)$. Similarly for defensive behaviour, as shown in (11b), the WTP can be estimated from costs incurred on defensive activities, Q_D, as a result from a marginal change in defensive behaviour brought about by a marginal change in pollution, (∂D/∂P). Hence, the WTP = $-Q_D(\partial D/\partial P)$. As equation (11c) shows, the WTP for a marginal change in exposure to pesticides equals the resulting change in sick time as a result of a change in sick time, ∂S/∂P, times the value of a marginal change in sick time, WTP_S. To a rational person the latter must

[8] The notation used here is similar to that used by Cropper and Freeman (1991).

in theory be equal to the marginal cost of bringing about a change in sick time [Cropper and Freeman (1991, p. 196)].

Harrington and Portney (1987) point out that since individuals do take defensive measures to mitigate or even prevent the effects of pollution, what is observed in cross-sectional studies is the total rather than the partial effect of pollution on health. For these reasons an alternative expression for WTP should be considered. Following Harrington and Portney (1987), WTP can be written as shown in Equation (12) which shows that WTP is the sum of the value of lost time w(dS/dP) and the disutility arising from ill health ($\partial U/\partial S$) (dS/dP)/λ plus the observed changes in averting and mitigating expenditures, Q_M (dM/dP) and Q_D (dD/dP) respectively.

$$WTP = w\frac{dS}{dP} + \frac{dM}{dP}Q_M + \frac{dD}{dP}Q_D - \frac{U_S}{\lambda}\frac{dS}{dP} \qquad (12)$$

The proof is shown in Appendix 2

where λ, the marginal utility of income, converts the disutility of illness $\partial U / \partial S$ into monetary values. An important difference between (12) and equations (11) is that as Cropper and Freeman (1991) show is that the WTP Equation (12) consists of total derivatives while Equations (11) consist of partial derivatives. Furthermore, in Equations (11), the three approaches have been derived separately while in (12) all the three approaches are in one equation. In fact, (11c) is similar to (12) because, it too, shows the direct (contingent valuation) question approach. However, Equation (12) goes further in showing the various components an individual is likely to consider in deciding on his WTP bid[9].

According to Equation (12), the true WTP (which is the direct CV approach) to avoid an increase in pollution, therefore, consists of the amount resulting from the COI expenditures (the first two terms on the RHS) plus the amount resulting from defensive behaviour expenditures (the third term) and the monetary value of the disutility arising from pollution induced illnesses (the fourth term). An individual directly asked, using the CV approach, for his/her WTP to avoid direct exposure to pesticide pollution may consider all expenditures shown in Equation (12) in revealing his/her WTP bid.

[9] See Kenkel (1994, p.6) who also states that theoretical models suggest that WTP reflect these four components.

Equation (12) also implies that only when the defensive measures undertaken are inadequate that the first two terms and the fourth term can exist. On the other hand, if defensive measures undertaken to prevent total exposure are sufficient, then there will only be defensive expenditure. Hence, depending on the adequacy of the defensive expenditures, the first two terms and the last term can be large or small. If defensive expenditure undertaken is small (inadequate) then the first two terms and the last term are large, and vice versa. Hence, as shown by Chestnut et al., (1988), defensive expenditures are a good measure of the WTP, when the defensive expenditures undertaken are sufficient to reduce or avoid all illnesses and loss of utility.

According to Harrington and Portney (1987) if $dS/dP > 0$, then the marginal WTP in CV studies always exceeds the sum of changes in defensive expenditures and the cost of illness. Only if this derivative is negative is the sum of the COI and defensive expenditures an overestimate. Harrington and Portney (1987) compared their results with those obtained by Courant and Porter (1981) who investigated the suitability of defensive expenditures alone as a measure of the benefits of environmental improvements. Courant and Porter (1981) showed that defensive expenditures over-or under-estimated WTP although an underestimate would be the most likely outcome. The only way that defensive expenditures can exceed CV WTP is for the dS/dP term to be negative (Harrington and Portney, 1987). In other words, individuals would have to respond to an increase in pollution by increasing defensive expenditures so that there are no health effects among those exposed to pollution. Likewise, the only way the COI approach can overestimate the CV WTP is for the dD/dP term to be negative (Harrington and Portney, 1987). Furthermore, they point out that “although nothing in the model prevents either of these outcomes, both would be extremely unlikely in practice”.

3. EMPIRICAL EVIDENCE SHOWING THE RELATIONSHIPS BETWEEN THE THREE APPROACHES

In this section, the above-mentioned three valuation approaches are employed to estimate the costs of direct exposure to pesticides and determine whether the CV results exceed the COI and defensive behaviour expenditures as demonstrated in Equation (12). For this purpose a field study was undertaken in Sri Lanka covering five regions in the Central and North-Central Provinces in the summer of 1996. A questionnaire was used to collect data from 203 farmers on the private costs[10] of ill health (including all private medical expenditures and lost time) and defensive expenditures resulting from direct exposure to pesticides. CV bids were also obtained using the same questionnaire [Wilson (1998) provides further details of the survey]. The data collected show that although farmers take precautionary measures whilst handling and spraying pesticides, they suffer from many adverse health effects, thus incurring large medical and time costs. This implies that, although farmers have taken precautions to minimise or avoid ill health arising from direct exposure to pesticides, such measures are inadequate and hence they incur medical and time costs due to pesticide exposure related illnesses. In such cases, farmers also suffer from pain, stress and discomfort. These costs are not captured by the COI approach. However, a farmer, in answering a CV question for WTP to avoid exposure to pesticides is likely to take into account all these costs in stating his/her CV WTP bid. This was evident during the field survey.

Several empirical studies in the past have compared the relationships between the three valuation approaches discussed in this paper. A study by Rowe and Chestnut (1984) showed that CV bids exceed the COI estimates. Berger et al., (1987) and Dickie and Gerking (1991), too, showed that CV bids always exceeded private COI estimates. However, Loeman et al., (1979) provided some weak evidence against the hypothesis that CV bids exceeded COI values. Perhaps this is a case where dD/dP is negative, as pointed out by Harrington and Portney (1987). Chestnut et al., (1996) provided further evidence to show that the CV WTP approach is more comprehensive than the traditional COI approach. Studies have also been carried out to compare the CV approach with the defensive behaviour approach. Dickie et al., (1986, 1987) showed that the mean defensive behaviour values are higher than the CV estimates. However, it has been pointed out that these defensive behaviour estimates should be regarded as upper bound estimates, since the full costs of joint products (such as in the use of an air conditioner) have also been taken into account. Ideally, only the cost of air conditioning that benefited the individual against air pollution should be calculated. Moreover, the results must be regarded as preliminary, due to the small sample sizes that were involved. Interestingly, Murdoch and Thayer (1990) compare defensive expenditure estimates for reducing the predicted increases in the rates of nonmelanoma skin cancers with the COI estimates and show that the COI estimates are more than double the estimates of the defensive behaviour approach.

[10] Only private costs of ill health are considered because treatment in government hospitals in Sri Lanka is provided free of charge.

The results of the Sri Lanka field study (Table 1), too, show differences in costs among the three approaches. As can be seen in Table 1, CV bids are larger than the COI or defensive behaviour expenditures or even both estimates combined.

The CV question obtained WTP bids to avoid direct exposure to pesticides while the COI and the defensive behaviour approach estimates are interpreted for a reduction in direct exposure to pesticides. This is because when defensive behaviour expenditure is inadequate, then there are costs arising from increased illnesses as well. Hence, both defensive behaviour costs as well as costs resulting from ill health. It must be pointed out that the field study was unable to take into account all the costs, especially the time costs (such as time spent purchasing and maintaining protective gear) for the defensive behaviour approach. Some of the benefits arising from goods that have joint benefits, such as an expensive sprayer that is both efficient as well as preventing pesticides leaking into the body of the user, too, could not be taken into account due to difficulties in calculating such costs. However, despite some of these important costs not being taken into account, the estimated CV bids are still large enough to exceed estimates from both the COI and the defensive behaviour approaches.

Table 1: Comparing the Three Approaches Using Field Survey Data

Symptom	Sample Size	Mean Yearly CVM bid (RS)	Mean yearly Private COI expenditures (RS)	Mean Yearly Private DB expenditures (RS)
Ill Health resulting from direct exposure to pesticides	203	11,471.18	5,465.54	405.14
		95% Confidence Intervals		
		$9{,}726.14<\mu_x<13{,}216.21$	$4{,}484<\mu_x<6{,}447.08$	$293.01<\mu_x<517.26$

Survey Period: July to September, 1996

Note: The 95% confidence intervals in Table 1 indicate that 95 out of 100 times such intervals will include the true μ_x.
DB = Defensive Behaviour
COI = Cost of Illness
CVM = Contingent Valuation Method

These results confirm the hypothesis that the CV WTP bids exceed the sum of changes in defensive behaviour expenditures and the costs of illnesses combined. This is because, as shown in Equation (12), a person affected by direct exposure to pesticides when asked how much he/she would be willing to pay to avoid ill health resulting from direct exposure to pesticides, is likely to consider all the costs of illnesses (including money and time costs), intangible costs (such as pain, stress, suffering and discomfort) and the defensive costs incurred in revealing his/her true WTP to avoid direct exposure to pesticides. Hence, the hypothesis that CV bids are expected to exceed all costs of illnesses and the defensive costs combined. This result is also another way of confirming the validity of the CV exercise.

While on theoretical grounds, CV approach estimates are expected to exceed the costs of ill health plus the costs of defensive behaviour, we cannot be sure that empirical values are an accurate measure of the loss of welfare due to illness. CV WTP estimates provided by respondents in an interview may overestimate their WTP to avoid ill health arising from pollution for several reasons. One major reason is that biases can arise in CV studies which can influence the decisions made by a respondent. Many types of biases have been mentioned in the literature. For example, see Mitchell and Carson (1989), NOAA (1993), Hanley and Spash (1993) and Kenkel et al., (1994). One main bias is 'strategic' bias where if respondents believe the questions to be hypothetical, they have little incentive to give accurate information concerning their maximum WTP. On the other hand if they see the exercise as playing an important role in future policy making, and not hypothetical, respondents may have incentives to strategically misrepresent their values. Whittington (1998) also talks of 'compliance bias' in developing countries. For a full discussion on biases, see Wilson (1998). It is, therefore, extremely important to consider these issues and take appropriate measures when conducting studies of this nature.

4. CONCLUSIONS

In the above discussion a WTP model was developed to show the relationships between three valuation techniques used to determine WTP for pollution control. It was also shown in the model that the CV approach exceeds the sum of COI and defensive behaviour approaches. This theoretical argument was evaluated empirically by recourse to data (on the three approaches) obtained from a field survey of Sri Lankan farmers exposed to pesticides during handling and spraying. The results of the field survey, too, confirm the hypothesis that CV WTP bids exceed the COI and the defensive behaviour expenditures.

APPENDIX 1

Consider the minimum expenditure function which is shown in (10):

$$E = \underset{X,D,M}{Min}\left\{XQ_X + DQ_D + MQ_M - w(T - S(E(D,P),M)) + \lambda(\overline{U} - U(X, S(E(D,P),M)))\right\} \quad (1)$$

Applying the envelope theorem to (1) we get

$$\partial E/\partial P = w(\partial S/\partial P) - \lambda(\partial U/\partial S)(\partial S/\partial P) \Leftrightarrow (\partial S/\partial P)[w - \lambda(\partial U/\partial S)] \quad (2)$$

$$\partial E/\partial S = w - \lambda(\partial U/\partial S) \quad (3)$$

Then taking the first order conditions for expenditure minimisation we get:

$$\partial E/\partial D = Q_D + w(\partial S/\partial D) - \lambda(\partial U/\partial S)(\partial S/\partial D) = (\partial S/\partial D)[w - \lambda(\partial U/\partial S)] + Q_D = 0$$

From which you get

$$[w - \lambda(\partial U/\partial S)] = -Q_D(\partial D/\partial S) \quad (a)$$

$$\partial E/\partial M = Q_M + w(\partial S/\partial M) - \lambda(\partial U/\partial S)(\partial S/\partial M) = (\partial S/\partial M)[w - \lambda(\partial U/\partial S)] + Q_M = 0$$

From which you get

$$[w - \lambda(\partial U/\partial S)] = -Q_M(\partial M/\partial S) \quad (b)$$

Now substituting (a), (b) and (3) in (2) as shown below, we get the results shown in (11)

Substituting (a) in (2)

$$\boxed{\partial E/\partial P = -Q_D(\partial S/\partial P)/(\partial S/\partial D) = -Q_D(\partial D/\partial P) > 0}$$

Substituting (b) in (2)

$$\boxed{\partial E/\partial P = -Q_M(\partial S/\partial P)/(\partial S/\partial M) = -Q_M(\partial M/\partial P) > 0}$$

Substituting (3) in (2)

$$\boxed{\partial E/\partial P = (\partial S/\partial P)/(\partial E/\partial S) = (\partial S/\partial P)WTP_S}$$

APPENDIX 2

Consider the total differential of S, where $S = S(E(D,P),M)$

$$dS = (\partial S/\partial D)dD + (\partial S/\partial P)dP + (\partial S/\partial M)dM \tag{A}$$

Then taking the total derivative of S with respect to P we have:

$$dS/dP = (\partial S/\partial M)(dM/dP) + (\partial S/\partial D)(dD/dD) + (\partial S/\partial P) \tag{B}$$

We can deduce the partial derivative, ($\partial S/\partial P$)

$$\partial S/\partial P = (dS/dP) - (\partial S/\partial M)(dM/dP) - (\partial S/\partial D)(dD/dP) \tag{C}$$

Then from (11c) we know

$$WTP = \partial S/\partial P WTP_S$$

And from Appendix 1 we know

$$WTP = \partial S/\partial P(w - m\partial U/\partial S) \tag{D}$$

Substituting (C) in (D), we get:

$$WTP = (dS/dP) - (\partial S/\partial M)(dM/dP) - (\partial S/\partial D)(dD/dP)[(w - m\partial U/\partial S)] \tag{E}$$

Rearranging we have

$$WTP = wdS/dP - [(\partial S/\partial M)(dM/dP)][(w - m\partial U/\partial S)] - [(\partial S/\partial D)(dD/dP)][(w - m\partial U/\partial S)]$$
$$- m[(\partial U/\partial S)(dS/dP)] \tag{F}$$

From the first order conditions in (10) we get

$$Q_M + w\partial S/\partial M - m\partial U/\partial S \partial S/\partial M = 0 \Leftrightarrow -Q_M = (w - m\partial U/\partial S)\partial S/\partial M \tag{G}$$

$$Q_D + w\partial S/\partial D - m\partial U/\partial S \partial S/\partial D = 0 \Leftrightarrow -Q_D = (w - m\partial U/\partial S)\partial S/\partial D \tag{H}$$

Then by substituting in (F) we get

$$\boxed{WTP = w\frac{dS}{dP} + \frac{dM}{dP}Q_M + \frac{dD}{dP}Q_D - \frac{U_S}{\lambda}\frac{dS}{dP}}$$

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